THE INFLUENCE OF FORCED RESPIRATION ON PSYCHICAL AND PHYSICAL ACTIVITY.

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The effect of various psychical and physical activities upon respiration has been investigated by psychologists and physiologists, and intimate relations have been established. These relations, however, have been studied but rarely from the reverse standpoint, though there is good ground for deeming such a study profitable.[1] The following study is an attempt to investigate one of these reverse relations, that, namely, which exists between voluntarily increased rapidity of breathing and various types of physical and psychical activity.

INTRODUCTORY.

A review of the physiology of respiration shows that forced respiration might influence these activities especially in two ways: by increasing the amount of available oxygen in the blood or tissues, and by influencing the rate of circulation and the composition of the blood.

With regard to the first, it is obvious that since the haemoglobin of the blood is normally nearly saturated with O, no amount of forced breathing can greatly increase the amount of O in the blood and so in the tissues unless there is a concomitant change in the rate of circulation. Yet the amount of CO_2 eliminated might be increased by thorough ventilation with normal circulation, and so a relative oxygenation be accomplished. A practical example of the reverse case occurs in "loss of wind" in running, which is often due, not to lack of air inhaled, but to lack of heart power to drive the oxygen-carrying blood to the tissues. It is further clear that no amount of fast breathing or rapid circulation can wholly atone for a paucity of red corpuscles and haemoglobin.

The effect of forced respiration on circulation may be either direct (impeding or assisting the flow of blood to and from the heart) or indirect, by the reaction of the changes in the compo-

[1] This topic was suggested to the writer by President Hall, who has treated many of the more general aspects of the relation of respiration and the air to mental activity, in his class lectures on Cosmology, and I desire here to acknowledge my indebtedness to him and to the subjects who have spared time for my tests.

sition of the blood upon the nervous centers presiding over this function.

The principle that inspiration increases the flow of blood from the brain, while expiration hinders it to such an extent that the brain is raised with each expiration, may perhaps account for a peculiar feeling in the top of the head observed by several of the subjects of our experiments during the forced breathing, and described as an odd mixture of pressure and vacuity.

The general relation of the activity of the nervous centers for circulation and respiration to the proportion of CO_2 in the blood is too well known to need illustration, but the conditions in apnœa (momentary cessation of respiration) are not altogether clear, and as this appears to be a regular sequel of such forced breathing as we have used, it may be worth a little consideration. There are two main theories, the chemical and the mechanical.

The first is especially supported by the work of Ewald, who claims that after a period of forced breathing, the system and the blood become hyperoxygenated. The medulla is thus quieted by the presence of much O and little CO_2, and there is a more or less complete cessation of respiratory movements. This is borne out by the fact that the fœtus in its prenatal condition is kept from breathing by the presence of blood richly charged with O, and by certain experiments of Ewald who found that venous blood in apnœa contained less than the normal amount of O, and by Pflüger's experiments showing a slowing of the capillary circulation during apnœa so that a larger amount of O may be taken up by the tissues.

Those who hold the mechanical theory that apnœa is caused by a weariness of respiration (a fatigue, reacting on the medulla by the vagus nerve, which suppresses its activity), argue that it cannot be proved that the blood is hyperoxygenated, and that, further, artificial forced breathing of H by animals causes apnœa.

Gad, Knoll and others hold that the cause is chemical, but due not to hyperoxygenation of the blood, but to the presence of much atmospheric air in the alveoli, which are able to arterialize the blood for some time, but at the normal rate.

Reichert, in the "American Text Book of Physiology," in commenting on this mooted question concludes that "in view of the fact that apnœa from breathing O is much more marked than from breathing H, it seems evident that apnœa may be due to either gaseous or mechanical factors alone or to both, the latter producing a quicker and more lasting effect."

A recent work on respiration, and one which touches some points identical or closely related to those taken up in the pres-

ent study, is that of William Marcet, entitled "A Contribution to the History of the Respiration of Man," London, 1897.

Marcet is interested in the medical aspects of respiration, and concerned with the effect of mountain climbing, high altitudes, temperature, food, exercise, etc., on respiration, and the effects of forced respiration or volition, towards forced respiration on muscular power. He studied also the after stages in each case, and tested by elaborate apparatus the amounts of air breathed and the proportions of O consumed and CO_2 eliminated in the various tests. He demonstrates the apnœic pause after forced breathing and finds also a second short period of increased breathing always following the apnœa. He finds that an excess of CO_2 is eliminated from the blood by the forced breathing and an excess of O of from 4.7 to 36.4 cc. per minute, is absorbed under the same conditions, thus strongly supporting Ewald's theory of apnœa. It is also an important fact that the same rate and depth of respiration, which in forced breathing gives rise to apnœa, when it occurs as a natural concomitant of muscular exercise, excites no fatigue and is followed by no apnœa.

Active volition towards some form of exercise, locomotion, lifting, etc., gives on the other hand tracings with after-stages like the forced breathing curves. Marcet finds that forced breathing nearly doubles muscular power and explains it by the fact that the increased absorption of O takes place mainly in the cerebral motor centers, a point of great interest if it shall eventually be confirmed. His conclusions as to apnœa are peculiar. Like Ewald, he finds more O absorbed, but unlike him, argues (from his experiments) that apnœa is purely an after effect of volition. Only when there is volition toward *muscular* contraction does apnœa occur. Under these circumstances, the cause of the increased breathing is a direct action of a motor center (the one that would be concerned in the muscular contraction if one were made) upon the respiratory center. In forced breathing many accessory muscular contractions are made and the overflow to the respiratory center is from the centers involved in them. Now when volition toward muscular contraction is suddenly suspended (or at the end of the forced breathing) the respiratory center is left unsupported, and missing the added stimulus before received, is sluggish in action, and apnœa results.

Experiments on the Effect of Forced Respiration on Physical and Mental Processes.

The writer's experiments were carried out upon six subjects, all university students (five Americans and one a Japanese), between March 2nd and June 14th of the current year. They

have been for the most part somewhat rough in character, intended rather to blaze a path in a new direction and to find general bearings than to make exact determinations of particular points.

The tests of physical and mental conditions used were:

1. Dynamometer grip continued through 30 seconds.
2. Adding of digits.
3. Dealing of sixty cards into two piles.
4. Simple reaction time to sound.
5. Discrimination and choice tested by the sorting of sixty cards according to color, red and black.
6. Memory span.
7. Precision of rapid touches.
8. Threshold in discrimination of gray.

Each subject on each day went through the same series of tests both in normal condition and after two minutes of forced breathing. In the latter case each test was made if possible entirely within a single minute directly following the breathing.[1] If the test occupied a longer time, additional breathing periods were inserted. The tests were made on eight days for each subject, exclusive of the preliminary trials which were designed to eliminate most of the practice effects. On four days the normal tests were made first, on alternate days the forced breathing first, thus balancing in the totals any daily effects of warming up, practice or fatigue. Each complete series occupied one hour.

On another day, tracings of the subjects breathing under the various conditions were taken by means of two pneumographs (of the pattern devised by Dr. Fitz, of Harvard,) and a continuous paper kymograph driven by a water motor. Each tracing shows the chest and abdominal breathing and a time curve with 2 sec. intervals.

These tracings reveal a more or less complete apnœic pause (an extreme case lasting over two minutes) after the forced respiration. Differences in rate, depth and character of the movements in the forced period, and considerable individual differences in the types of normal breathing are also brought out, *e. g.*, variations in the rate of the forced breathing among the subjects are from 19 to 36 per minute; variations in the form are also marked, some subjects increasing the chest movement, some the abdominal; for some, pure apnœa is replaced by very slow, slight respirations with long expiratory pauses; some

[1] In comparing the results of these experiments with those of Marcet it should be remembered that his tests of strength, etc., were made after normal automatic respiration had been established, while these were made as soon as possible after the cessation of the forced breathing.

normal curves show predominance of diaphragmatic, some of costal breathing.

The subjective effects of the forced breathing were in general: more or less dizziness, blackness before the eyes, tingling or prickling sensations in the hands and feet, and a feeling of confusion coupled with energy. Not all these were experienced at once, and all passed away with the cessation of forced respiration. There was often a secondary effect of exhilaration.

Before the special tests, the lung capacity was each day tested with a spirometer. The highest and lowest amount registered by the spirometer and also the average for each subject will be found in Table I, together with his height and weight.

TABLE I.

SUBJECT.	HEIGHT.	WEIGHT.		SPIROMETER.		
	Cm.	Lbs.	Oz.	Min. Cu. in.	Max. Cu. in.	Av. Cu. in.
J	172.3	137	6.5	190	220	207
Y	156.3	113	8.0	162	180	175
G	176.9	159	14.0	230	259	244
H	171.6	143	8.0	227	255	240
P	170.3	167	10.5	200	240	221
S	168.1	159	2.5	237	257	247
Average	169.2	146	1.6	208	235	222

The first of the regular daily tests was that with the *Dynamometer*. The apparatus was essentially that used by Bryan,[1] but only one hand was tested, and an attachment was made by which a reduced tracing of the fatigue nerve could be obtained. The subject maintained a maximum pressure for 30 seconds, the height of the mercury column being also recorded by the experimenter at the beginning and end of this period, and the form of the fatigue curve being registered on a kymograph drum. The results of these tests show a more or less decided gain both in initial strength and in endurance after the forced breathing. The average numerical readings in centimeters are given in the following Table.

One subject (Y) was unable to hold the mercury for the full period of 30 seconds. His curves showed a peculiar, sudden drop at about the 15th or 20th second. This was occasionally the case with subject H.[2] In further tests on subject Y at the close of the regular work, he was found able to sustain the mercury for the full period of 30 seconds after forced breathing, but was

[1] This JOURNAL, V, 196.

[2] Something of the same kind was observed by Lombard in his study of ergograph curves. This JOURNAL, III, 24.

TABLE II.[1]

Dynamometer.

SUBJ.	NORMAL.				FORCED.			
	Beginning.	M. V.	End.	M. V.	Beginning.	M. V.	End.	M. V.
J	74.3	4.0	60.6	3.3	73.1	6.9	60.5	4.2
Y	[71.5]	[7.5]			[73.6]	[6.0]		
G	91.4	5.4	68.4	3.0	94.0	4.9	73.3	3.7
H	75.7	3.9	55.5	4.5	79.0	5.0	58.5	4.5
P	82.5	4.3	53.6	6.9	90.5	2.6	58.8	2.3
S	84.1	9.0	58.0	9.5	85.5	8.0	56.3	10.9
Av.	81.6	5.3	59.2	5.4	84.4	5.5	61.5	5.1

still unable to do so in the normal condition. This affords an interesting support to the general conclusions attained. The figures for H are for four days only.

The curves given by this apparatus show great variety from subject to subject, but those of any single subject are extremely uniform in character as has been found by others in similar studies.

The effects of practice, warming up, and fatigue were excluded from the final results as before explained. Averages of the results according to the order specially made to discover such effects show that in the dynamometer test these factors hardly enter at all, or balance each other in amount.

Adding. The next test, taking them up in the order given to the subjects, was adding. Eight columns of 17 numbers each were added each day, the time being taken with a stop-watch and the correctness of the results being noted. The columns all footed up between 131 and 142, and were of approximately equal difficulty. The results show no certain difference between the times required for adding after normal and after forced breathing; two subjects add slightly faster, and four slightly slower after the breathing, while the net result is .12 seconds faster for the breathing. The breathing also did not affect the correctness of the work. Interesting individual differences are found, and a strong practice curve shown.

Rapidity of Movement, Card Dealing. The next test was designed to measure the rapidity of movement, and consisted of dealing a pack of 60 specially prepared cards into two piles. Such card tests are of little use to people who lack sufficient manual dexterity to deal them one at a time. This was the case with one at least of the subjects, and in all cases there was a strongly marked practice curve.

[1] M. V. in this and subsequent tables represents the mean variation of the eight daily records from their average.

The dealing test also gave negative results, being faster under forced breathing for three subjects and slower for two, with total averages equal. The sixth subject was so irregular in dealing that a substitute test was provided, consisting simply of making small crosses with a pencil at maximum speed for 30 seconds. This was not a very satisfactory test, but showed, so far as it showed anything, the same negative results as the other.

Simple Reaction Time. The fourth test was the simple reaction to sound. At first this was taken by means of an electric tuning fork, vibrating 100 times per second, writing through a small electro-magnetic signal on a smoked drum. For this method was later substituted the more accurate Hipp Chronoscope with a falling-ball stimulus. With the first apparatus from 30 to 40 reactions were made each day, with the Hipp 20.

The results show that five subjects average longer in reacting after the breathing, the sixth takes only 0.0004 longer in the normal condition, a difference so small as to be negligible. The average is 4.25 σ longer after forced breathing. The number of daily tests in which forced breathing lengthens the time is also greater than half, so that it is probably safe to say that forced respiration has some slight tendency to lengthen the simple reaction time.

The averages for reactions are here given:

TABLE III.[1]

Reactions.

SUBJECT.	NORMAL.	M. V.	FORCED.	M. V.	F-N.
	σ	σ	σ	σ	σ
J	145.0	7.9	147.0	13.2	2.0
Y	134.0	9.0	139.6	6.6	5.6
G	141.8	6.6	144.9	6.5	3.1
H	143.7	10.6	148.9	10.5	5.2
P	132.0	6.7	131.6	4.9	−0.4
S	141.6	4.0	151.6	4.5	10.0
Average	139.7	7.5	143.9	7.7	4.25

Discrimination Test, Sorting Cards by Colors. The second form

[1] Owing to a loss of some records, the mean variations in the *individual* reaction times of all the subjects cannot be given. Incomplete records for four subjects show an average of the mean variation in the reactions in normal condition of 13 σ, under forced breathing of 16 σ. The slightly greater variation in the latter case may be due to the fact that when using the Hipp Chronoscope, the subject was made to do forced breathing before each reaction. This, in itself, may have lessened the constancy of attention.

of card test is next in order. It consisted in sorting from four to six times the well shuffled pack of 60 cards into two piles, this time according to color—black and red—as a rough index of the discrimination time plus the above mentioned dealing time. Subjects were required to make a quick motion of correction in case a card was wrongly placed. The time was taken by stop-watch. The general remarks about the dealing test apply also here though to a less degree.

The results (v. Table IV) show on the average a slightly lower sorting time after forced breathing. This longer time, since the dealing test gave negative results, may be attributable to the more purely mental process of discrimination, but may be due, as suggested by the tests in discriminating grays, to poorer perception of the colors. Four of the five subjects show this tendency; the fifth leans very slightly the other way, while in the case of a sixth, the cards were again of no avail and a special discrimination test had to be arranged—reactions with right or left hand to two slightly different sounds. The results of the sorting test are given below in seconds.

TABLE IV.

Sorting 60 cards.

SUBJECT.	NORMAL.	M. V.	FORCED.	M. V.	F-N.
J	53.06	2.05	54.45	1.44	1.39
Y	45.06	2.33	45.61	1.52	.55
G	50.04	1.39	49.64	0.62	.40
H					
P	41.27	1.62	42.41	2.32	1.14
S	45.34	2.33	45.79	1.83	.45
Average	46.95	1.94	47.54	1.54	0.706

The discrimination tests on subject H with the chronoscope, confirmed the general result from the card sorting. The average normal time was $340 \pm 2\sigma$ with an average mean daily variation of 41σ; the average after forced breathing was $356 \pm 7\sigma$ with an average mean daily variation of 45σ.

Test No. 6 was a test of *memory*. At first series of ten printed nonsense syllables were exposed for the subject's study during a period of 30 seconds. This method was found poor, however, in practical working, since the subjects changed their method of learning; now visualizing, now committing by articulating, now by sound, and now by association; and the results were not at all uniform. A method free from most of these defects was found in testing the memory span with numerals read by the experimenter in time with a pendulum swinging once in .74 sec. This insured uniform speed. Nine numerals

were commonly used, but ten were necessary for subjects P and S after a day or so of practice. The results were obtained by recording the number of errors made by the subject, in writing the numbers immediately after dictation. Errors in position as well as in the digits themselves were counted. Unfortunately no record of the number of transpositions (the most frequent error) was kept.

With the exception of one subject (Y, a Japanese), the results uniformly show more errors after the breathing and the final average points in that direction. The one exception may be due to a fact revealed towards the end of the experiment that the memorizing was sometimes done in English, sometimes after translation into Japanese. I have therefore omitted his results in the average.

TABLE V.

Memory.

SUBJECT.	NORMAL.	M. V.	FORCED.	M. V.
J	18.50	3.12	19.70	2.57
Y	[25.00]	[4.25]	[22.60]	[2.22]
G	4.87	1.59	6.62	3.62
H	5.50	2.40	7.46	3.04
P	2.13	1.87	4.50	2.50
S	2.37	1.62	3.37	2.00
Average	5.56	2.12	6.94	2.74

The test for *precision* of aim caused considerable trouble before a suitable one was found. The form of test finally used seems to combine all the necessary points, viz.: the same frequency and speed in the thrusting movement, impossibility of correction by practice, an easy evaluation of the results, and the securing of a large number of tests without too great waste of time. It consists in having the subject try to touch, with a lead pencil, moving it in time with the beat of a .74 sec. pendulum, a series of ten small crosses irregularly placed on a sheet of paper, the pencil being raised each time to the height of the shoulder. This process was repeated, making a total of 20 thrusts after each form of breathing. The error is given in the table in millimeters.

The results from this test show that while, as would be expected, the error of each single thrust is quite variable, the average errors of a series of 20 thrusts are an almost constant quantity for each subject after the first practice effect has passed. The results also show a clear and regular increase in the errors after forced breathing.

Table VI shows the general averages for each subject, and the

averages of the daily mean variations. The probable errors of the general averages, though not given in the table, are very small, and justify the conclusion that forced breathing increases the error.

TABLE VI.

Precision.

SUBJECT.	General Average.				Average of Daily M. V.	
	Normal Breathing. Mm.	M. V. Mm.	Forced Breathing. Mm.	M. V. Mm.	Normal Breathing. Mm.	Forced Breathing. Mm.
J	4.05	0.39	4.88	0.43	1.80	1.89
Y	3.93	0.46	4.51	0.47	1.62	2.18
G	5.30	1.09	5.51	0.66	2.82	1.95
H	6.18	0.69	6.61	0.89	2.65	2.65
P	5.02	0.67	5.99	1.01	2.64	2.74
S	4.54	0.24	4.95	0.24	2.35	2.44
Average	4.84	0.59	5.41	0.61	2.31	2.31

The order had considerable influence in this test, five out of six subjects being more accurate in the second half hour irrespective of whether the forced breathing tests came first or those with normal breathing.

Discrimination of Grays. The final test was intended to be more purely sensory than those which have been given. It was visual, and consisted in a determination of the just observable difference of grays. The apparatus was a modification of that used by Leuba, and described in this JOURNAL, V, 376. A rapidly revolving vertical pasteboard disk 368 mm. in diameter and pierced with 12 radial slits each, 138 x 13 mm. was interposed between the subject and the grays to be discriminated. The disk was covered with white (later light gray) paper, and arranged to slide vertically for a distance of 120 mm. The subject being seated before a tube 61 cm. long in front of the disk, looked through the tube and the disk at figures of various forms (square, triangle, hexagon, letter H, etc.), which were made of quite dark gray paper approximately 70 mm. square, and pasted in the center of a background of a very little darker gray paper 153 mm. square. These diagrams were 270 cm. beyond the disk. When the disk was low down in its slide, so that the subject looked through the upper part of it, the grays of the figure and background could not be distinguished, and the form of the figure could not be told. In making a determination, then, the disk was raised till the figure could be discriminated from its ground and correctly named, when the elevation of the disk in millimeters was recorded. The conditions of the tests allow the results only a

relative value because of variations in illumination. Constant lighting could not be secured in the present case, and often tests were thrown out on account of variations in the outdoor light during the eight or ten minutes used in the test. The results, however, are sufficient for a comparison of the effects of forced and normal breathing. In making the test, each subject on each day was given five diagrams in the first test, and the same five in the second, though altered in order and in their position in the holder. The results from this test were very striking.

The average for every subject, not only in the totals, but for every day's tests, shows that the diagrams appear later, more confused, and are distinguished with more difficulty after the forced breathing.

In these tests the subjects had curious illusions and apperceptive experiences, *e. g.*, two upright parallel lines were often declared with certainty to be the "H." These phenomena increased with the forced breathing, which was uniformly said to make the figures hazy and flickering, even to such an extent that after the given figure was recognized, it seemed to some subjects to slide and alter its position on the background. Others found that in forced breathing, the whole diagram suddenly shifted in color, being alternately black or gray, or again a gray would appear in the center and gradually spread out to the borders.

The *tests of the effects of forced breathing upon circulation* have been of a tentative nature and few in number. The pulse rate of the various subjects before, during and after the forced breathing was once counted, and showed a slight quickening during the second minute of breathing; but by two minutes of the cessation of the forced respiration, the pulse had usually fallen again to the normal rate. A couple of tests of the eye pulse were made with the plethysmograph,[1] but with negative results.

If we now sum up the general results of this study we find the effects of forced breathing to be

1. An apnœic pause, as observed by Marcet.
2. A feeling of dizziness and confusion, followed somewhat later at times by exhilaration and clearness.
3. Greater strength and endurance of grip, found also by Marcet, but after an interval in which breathing returned to the normal condition.
4. Slightly lengthened reaction time.
5. Decreased memory span.
6. Longer discrimination time.

[1] *Psychological Review*, IV, 120.

7. Less precision of movement.
8. Poorer visual discrimination.

The simple throwing of cards in two piles and adding are apparently uninfluenced. Whether with more extended experiments this would be the case cannot now be asserted, but, these apart, the results seem to point to an improvement of the muscular mechanism, as the expense of the mechanisms of control and of the higher functions generally.

It would be interesting to follow the subject into the fields of early philosophy, where, as every one knows, breathing and soul have often been practically synonymous, and into the modern oriental cults where proper breathing is regarded as the road to insight and inspiration, and into the hygienic developments of respiratory gymnastics in the modern "deep breathing" schools, and among the "Ralstonians," but these are all quite beyond the scope of the present paper, which is confined to the report of experimental pioneering.